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PREFERRED FREQUENCY BANDS FOR RADIOLOCATION SERVICE BETWEEN 40 --ETC(U)
JAN 80 W E KATZENSTEIN, R P MOORE
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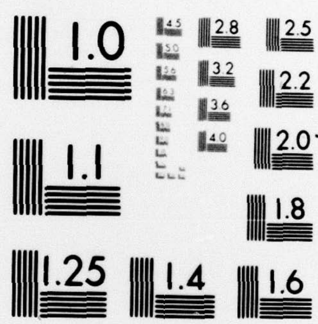

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Preferred Frequency Bands for Radiolocation Service Between 40 and 300 GHz

by
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JANUARY 1980

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Naval Weapons Center

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

FOREWORD

This study was undertaken by the Naval Weapons Center at the direction of the Director, Electromagnetic Spectrum Management, Office of the Chief of Naval Operations (OP-941F), under Task X0738100 in support of the U.S. Navy preparatory effort for the 1979 General World Administrative Radio Conference (GWARC) to be held in Geneva, Switzerland, in 1979. This document was approved at the Special Preparatory Meeting (SPM) of the International Radio Consultative Committee (CCIR) at Geneva, Switzerland, November 1978, as source material for the SPM Report. The SPM Report provides the technical bases for the considerations of the GWARC.

The GWARC will consider allocation of bands above 40 GHz to the various services. This document states and provides technical justification for preferred frequency bands for the radiolocation service between 40 and 300 GHz.

This report has been reviewed for technical accuracy by members of study groups I and IA of the United States' CCIR structure and by John B. Seybold of the Naval Weapons Center, in addition to the technical approval it received at the SPM.

Approved by
G. R. SCHIEFER, *Head*
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6 January 1980

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(U) *Preferred Frequency Bands for Radiolocation Service Between 40 and 300 GHz* (U), by West E. Katzenstein and Robert P. Moore, China Lake, Calif., Naval Weapons Center, January 1980. 6 pp. (NWC TP 6134, publication UNCLASSIFIED.)

(U) The current International Table of Frequency Allocations identifies no frequency bands for radiolocation devices above 40 GHz. This document discusses the advantages of millimeter wavelengths to the radiolocation services and factors affecting the choice of bands for radiolocation. It is concluded that preferred bands for radiolocation exist in the centers of the atmospheric propagation windows between 40 and 300 GHz, namely in the vicinity of 70, 95, 140, and 240 GHz. Other bands removed from the propagation windows are of value to short-range applications of radiolocation.

INTRODUCTION

Research and development work is being carried on for the use of frequency bands above 40 GHz for the radiolocation service. Activities have been concentrated in the windows of 35, 70, 95, 140, and 220 GHz because of the performance limitations imposed on this service by atmospheric attenuation and weather effects at millimeter wavelengths.

MILLIMETER-WAVELENGTH ADVANTAGES TO RADIODETERMINATION SERVICES

Radiodetermination equipments operating at frequencies above 40 GHz offer the advantages of narrow antenna beams available from physically small apertures, potentially small equipment size, and large operating bandwidth. The narrow antenna beams will make possible improved angular resolution of targets. The larger bandwidth will allow improved range resolution, since a radiodetermination device can generally distinguish two objects separated by a minimum range of

$$\delta_R = \frac{c}{2B}$$

where

c = speed of light
B = bandwidth of the radiodetermination device

The narrow antenna beams and the large amount of available spectrum reduce the possibilities for interference, as will the generally larger atmospheric attenuation.

The most important advantage is the ability to obtain high resolution in small, easily transportable equipment. This has the potential to make practical, small, and low-cost imaging and detection systems for such applications as collision avoidance, aircraft navigation and traffic control, and harbor navigation and traffic control. With rapidly increasing band crowding at the lower frequencies and the increasing problems with collision avoidance, the exploitation of the potential offered by radiodetermination devices operating above 40 GHz becomes a matter of some urgency. Note that the current table of allocations identifies no frequency bands for radiodetermination services above 40 GHz.

Some possible radiodetermination applications are listed below.[1]

Low-angle tracking
Imaging
Ground mapping
Space object identification
Weather radar
Air-traffic control
Navigation
Obstacle detection
Harbor surveillance
Airport-surface detection
Landing aides

A number of radiodetermination equipments have been built operating above 40 GHz. Table 1 (see Footnote 1) gives some examples of equipment built in the United States, but it is by no means complete.

TABLE 1. Radiodetermination Devices (Operating Between 70 and 140 GHz).

Type and application	Appropriate frequency, GHz
Mapping radar	70
Search	70
Aircraft obstacle avoidance and aircraft instrument landing	70
Bistatic continuous wave radar for cross-section measurements	140
Instrumentation for basic millimeter radar studies, backscatter studies, etc.	95
Obstacle avoidance, sea clutter measurement	95
Space object identification	85
Arctic terrain avoidance	95
Airborne applications, instrument landing	95
Monopulse tracking investigations	70
Helicopter wire detection	95
Imaging	95
Continuous wave doppler radar	95

[1] S. L. Johnston. "Millimeter Radar," *Microwave Journal*, November 1977, pp. 16-28.

FACTORS AFFECTING THE CHOICE OF BANDS FOR RADIOLOCATION

Attenuation of electromagnetic radiation by the earth's atmosphere above 40 GHz is a highly structured function of frequency and can be significant, Figure 1.[2] Any service which is not short range in nature may benefit from use of the transmission windows, such as is found near 100 GHz.

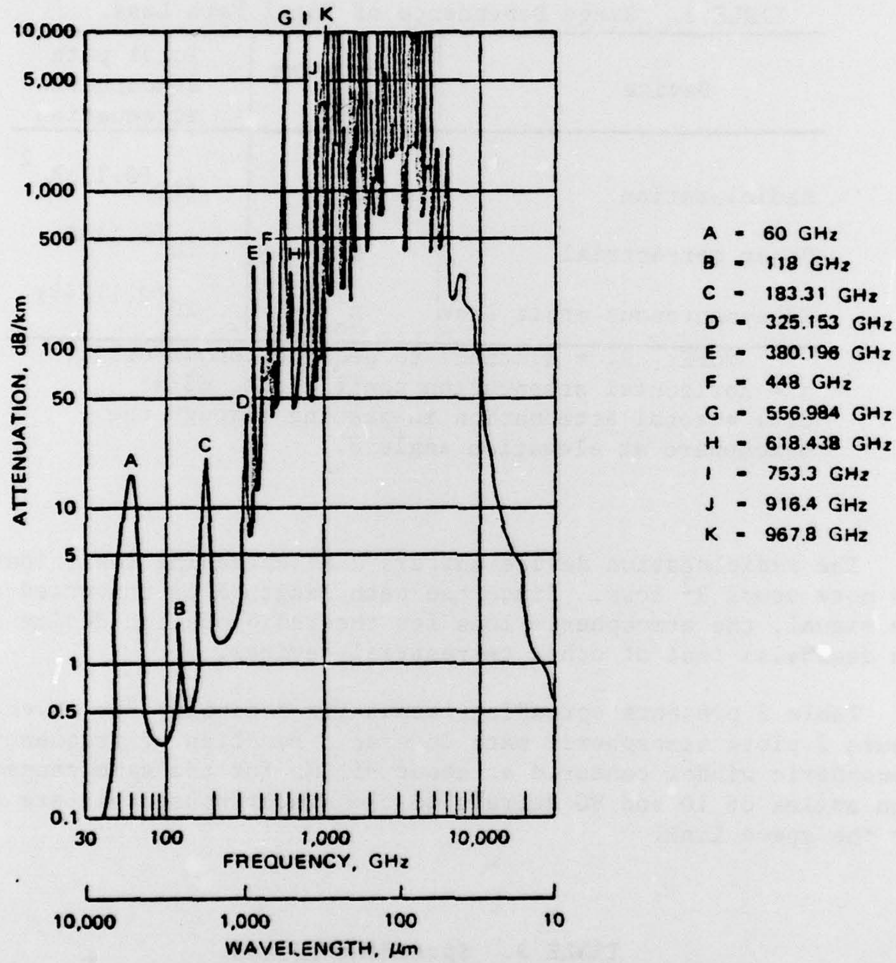

FIGURE 1. Atmospheric Attenuation at 1 atm Pressure, 293°K, and Absolute Humidity ρ = 7.5 gm/m^3.

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[2] S. A. Zhevakin and A. P. Naumov. "Propagation of Centimeter, Millimeter, and Submillimeter Waves in the Earth's Atmosphere," *IWZ Radiofizika*, Vol. 10, No. 9-10 (USSR, 1967), pp. 1213-1243.

Table 2 summarizes the equations governing spreading losses and total path atmospheric attenuations experienced by radiolocation devices, other terrestrial devices, and devices transmitting energy between the earth and geosynchronous orbit. The radiolocation device is assumed to be detecting an object at range R, and the other terrestrial system is transmitting information over a link of length R.

TABLE 2. Range Dependence of Total Path Loss.

Device	Spreading loss	Total path atmospheric attenuation
Radiolocation	R^4	$(10^{(0.1)\alpha R})^2$
Other terrestrial	R^2	$10^{(0.1)\alpha R}$
Geosynchronous orbit link	R_o^2	$10^{(0.1)\beta(\theta)}$

NOTE: R_o = distance to geosynchronous orbit; α = horizontal attenuation coefficient, dB/m; $\beta(\theta)$ = total attenuation in passing through the atmosphere at elevation angle θ.

The radiolocation device suffers a R^4 spreading loss, instead of the more usual R^2 loss. Since the path length R is traversed twice by the signal, the atmospheric loss for the radiolocation device is twice (in decibels) that of other terrestrial devices.

Table 3 presents spreading losses (in decibels) for several ranges. Figure 2 plots atmospheric path loss as a function of frequency in the atmospheric window centered at about 95 GHz for the same ranges. Elevation angles of 10 and 90 degrees to the synchronous orbit are assumed for the space link.

TABLE 3. Spreading Losses.

Device	Range, km		
	10	40	4×10^7
Radiolocation, dB	160	184	...
Other terrestrial, dB	80	92	...
Link to geosynchronous orbit, dB	...	...	152

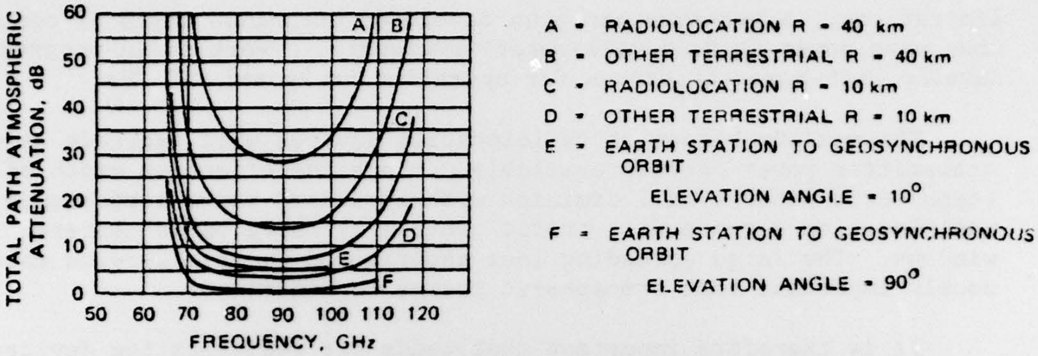

FIGURE 2. Total Path Atmospheric Attenuation Experienced by Terrestrial and Space Services Near 90 GHz.

It is clear that all three services may benefit from use of the atmospheric window. The spreading loss experienced by the radiolocation device is severe, which accounts for the large levels of transmitted peak power often used by this service. The total path atmospheric attenuation increases substantially, and the window rapidly becomes narrower with increasing range for the radiolocation device (see Figure 2).

The atmospheric attenuation experienced by the space service is not severe, even at an elevation angle of 10 degrees, which occurs at a latitude of 72 degrees. At elevation angles less than about 10 degrees, the atmospheric attenuation increases sharply at all frequencies, due to the longer amount of atmosphere intercepted. The window is flat and wide for this service (see Figure 2).

The other terrestrial devices experienced moderate amounts of atmospheric attenuation. The spreading loss experienced by the other terrestrial devices is significantly less than that experienced by the link to geosynchronous orbit or by the radiolocation device. It is likely that the maximum ranges used by the fixed service will be established by rainfall statistics and for the mobile service by line-of-sight considerations. These considerations may limit the narrowing of the atmospheric window, which is still broad at a range of 40 km for these services (see Figure 2).

Millimeter atmospheric absorption and rain attenuation, along with present power limitations of available millimeter sources and components, restrict current millimeter radiolocation applications to either short ranges or nonoperation in the rain. The continuing development of sources such as the gyrotron may eventually remove radio frequency source power

limitations. A gyrotron has been developed with 1500 watts of continuous wave power at 0.95-millimeter wavelength.[3] Work is in progress to develop high-power gyrotrons for operation at 94 and 120 GHz.

The maximum ranges of radiolocation devices will increase as greater transmitter power becomes available. Since the effective width of the atmospheric windows will diminish with increased range performance, the radiolocation service will profit greatly by using bands centered in the windows. The large spreading loss experienced by this service makes it doubly important that atmospheric losses be minimized.

It is therefore important that bands for radiolocation devices be centered in the transmission windows between 40 and 300 GHz (see Figure 1). The 95-GHz window is particularly valuable, since it offers the lowest atmospheric attenuation.

CONCLUSIONS

It is concluded that it is necessary to identify bands of operation for the radiolocation service in the 40- to 300-GHz region. (Note that the current table of allocations identifies no bands of operation for radiolocation devices above 40 GHz.) Because of power limitations, greater spreading loss, and high two-way atmospheric attenuation experienced in radiolocation operations above 40 GHz, bands for this service should be identified in the centers of the atmospheric windows between 40 and 300 GHz, namely in the vicinity of 70, 95, 140, and 240 GHz. The 95-GHz band is particularly valuable, due to the relatively small atmospheric attenuation at this frequency. Other bands for radiolocation should be identified to allow development of short-range applications such as ship and automobile collision avoidance.

[3] W. E. Fromm. "The Application Challenge of Millimeter Waves," *Microwave Journal* (November 1977), pp. 14-28.

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